SCIENCE OPPORTUNITY ANALYZER – A MULTI-MISSION TOOL FOR PLANNING

Barbara Streiffert, Carol A. Polanskey Taifun O'Reilly, Joshua Colwell

Jet Propulsion Laboratory
California Institute of Technology
National Aeronautics and Space Administration
4800 Oak Grove Drive, Pasadena, CA 91109-8099 USA
Barbara.Streiffert@jpl.nasa.gov (818) 354-8140
Carol.Polanskey@jpl.nasa.gov (818) 393-7874
Taifun.Oreilly@jpl.nasa.gov (818) 354-1170

Laboratory for Atmospheric & Space Physics
University of Colorado
Boulder, CO. 80309-0392 USA
Joshua.Colwell@lasp.colorado.edu (303) 492-6805

ABSTRACT

For many years the diverse scientific community that supports JPL's wide variety of interplanetary space missions has needed a tool in order to plan and develop their experiments. The tool needs to be easily adapted to various mission types and portable to the user community. The Science Opportunity Analyzer, SOA, now in its third year of development, is intended to meet this need. SOA is a java-based application that is designed to enable scientists to identify and analyze opportunities for science observations from spacecraft. It differs from other planning tools in that it does not require an in-depth knowledge of the spacecraft command system or operation modes to begin high level planning. Users can, however, develop increasingly detailed levels of design.

SOA consists of six major functions: Opportunity Search, Visualization, Observation Design, Constraint Checking, Data Output and Communications. Opportunity Search is a GUI-driven interface to existing search engines that can be used to identify times when a spacecraft is in a specific geometrical relationship with other bodies in the solar system. This function can be used for advanced mission planning as well as for making last minute adjustments to mission sequences in response to trajectory modifications. Visualization is a key aspect of SOA. The user can view observation opportunities in either a 3D representation or as a 2D map projection. The user is given extensive flexibility to customize what is displayed in the view. Observation Design allows the user to orient the spacecraft and visualize the projection of the instrument field of view for that orientation using the same views as Opportunity Search. Constraint Checking is provided to validate various geometrical and physical aspects of an observation design. The user has the ability to easily create custom rules or to use official project-generated flight rules. This capability may also allow scientists to easily impact the cost to science if flight rule changes occur. Data Output generates information based on the spacecraft's trajectory, opportunity search results or based on a created observation. The data can be viewed either in tabular format or as a graph. Finally, SOA is unique in that it is designed to be able to communicate with a variety of existing planning and sequencing tools.

From the very beginning SOA was designed with the user in mind. Extensive surveys of the potential user community were conducted in order to develop the software requirements. Throughout the development period, close ties have been maintained with the science community

to insure that the tool maintains its user focus. Although development is still in its early stages, SOA is already developing a user community on the Cassini project, which is depending on this tool for their science planning. There are other tools at JPL that do various pieces of what SOA can do; however, there is no other tool which combines all these functions and presents them to the user in such a convenient, cohesive, and easy to use fashion.

1.0 INTRODUCTION

Spacecraft tend to be "closed systems" similar in many ways to cars. Both have steering mechanisms; both need fuel and both have instrumentation. However, one major difference is the type of instrumentation. In cars instruments are generally indicators that give the driver information. On spacecraft they are scientific instruments that perform observations and collect science data. Another difference is that many spacecraft rely on commands sent from the ground to turn hardware on and off, perform diagnostic checks and start instrument observations because they don't carry human drivers to carry out these functions. They only have computers to relay the information to the spacecraft hardware.

In addition, spacecraft operations are tied to an event-driven timeline that is governed by orbital mechanics. It is not possible to stop the spacecraft to make decisions about the best observation to be made next. These characteristics along with the finite nature of spacecraft resources (there are no gas stations in space) place a premium on planning spacecraft activities. Science Opportunity Analyzer (SOA) is a software tool with broad functionality designed to meet this need for planning.

By planning, the scientist will be able to get the highest quality data from the best observations. To ensure that these criteria are met, the scientist needs to have information that shows that the planned observation not only meets with the scientific objectives, but also meets with reality. However, in the past, the science user has been left to develop ad hoc tools that are specific to a particular space mission for an instrument built solely for that mission. These tools have not allowed the users to share observation information easily and tend to be a bare minimum of what is actually needed. Generally, these tools don't communicate with other software tools that are used to collect and check the commands that are to be sent to the spacecraft. Science Opportunity Analyzer (SOA), a software tool, has been built to fulfill the need of assuring that the science objectives can be met while at the same time meeting the needs of sharing information and entering the observation into the pipeline that ultimately results in commands to the spacecraft.

For this tool to meet the needs of the user community, it has been important to find out what the end user needed. A methodology called "Quality Functional Deployment" (see, e.g., Belhe and Kusiak, 1996) or "Obtaining the Voice of the Customer" was used. A cross discipline group of scientists, software engineers and system engineers met and created an open-ended questionnaire and interviewed 40 selected stakeholders in the software. This group also developed a closed-ended set of questions (short answer, fill-in-the-blank, multiple choice, rank, etc.) as a check of the results of the interviews using the open-ended questionnaire. The results of the interviews were then transformed into required functional capabilities and ways to measure those functional capabilities. It was important for this group to continue in some way to insure that the software remained true to its charter. The software and system engineers formed the SOA Development Team, and developed the software requirements and the top-level design. The science members became members of the SOA Standing Review Board. The software requirements and the design reviews have been held before this evaluation board. In this way the software has continued to be implemented based on the "Voice of the Customer".

From the interviews several basic scenarios of how a science user would use a tool like SOA were developed. The following is one typical high-level scenario.

1. One or more time periods of opportunity that satisfy entered geometric criteria are found.
2. The science user selects one of the time periods and chooses to see a display of that time in either a 2-dimensional or a 3-dimensional view.
3. The user determines the time window with the most potential and proceeds to design the observation. During this time the user continues to check the display of the design to make sure that the design, as it unfolds, continues to meet the science objectives.
4. As part of the design process the science user chooses to have the tool check the design against spacecraft constraints. These constraints may be geometric in nature. For example, the instrument may not be able to have the Sun in its field of view without damaging the instrument. The constraints may be hardware state driven. In this case, an example would be that the spacecraft couldn't actually turn as quickly as desired.
5. The user may also select to look at data such as lighting angles or other geometric data dealing with the observation or the spacecraft trajectory to determine the value of the design.
6. After the design is constraint-free, the science user refines the design and saves it for future recall.
7. Finally, the user adds the design to the plan of activities that are to be sent to the spacecraft. Constraint checking will be performed again once all of the observations and other spacecraft tasks are entered in the plan of activities.

At any place in the scenario, the science user can go back to a previous step and make changes as needed or desired. SOA has been built to perform all of these tasks. It consists of six major functional areas: Opportunity Search, Visualization, Observation Design, Constraint Checking, Data Output and Communications.

Before proceeding with a more detailed description of the major functional areas, it is important to understand the process of sending commands to a spacecraft. At the Jet Propulsion Laboratory (JPL), this process is called the Uplink Process. It consists of engineering and science groups deciding on the tasks and observations that they want the spacecraft to perform. These tasks are defined and all of them are placed on a time-line that forms an operational plan for the spacecraft. The time-line is refined so that it contains no constraint violations. In order to eliminate the conflicts the tasks in violation are sent to their respective submitters for modification and then resubmitted. It is important that the task/observation is initially constraint free or it is possible that the task/observation will be removed from the plan. All of the functional areas in SOA support an observation being added to the operational plan.

2.0 SCIENCE OPPORTUNITY ANALYZER (SOA)

SOA is a java-based application that runs on Suns under Sun Solaris and PCs under NT, XP, 2000 and Linux. It is a multi-mission tool and can be easily configured for different missions. It utilizes Swing, Java 3-D, Java 2-D and XML extensively. SOA uses a hierarchical approach to objects so that project specific objects can be easily added. The project specific objects form the lowest tier of the hierarchy. SOA has tabs (see Figure 2.1) that represent the major work areas of Opportunity Search, Observation Design (Visualization and Spacecraft Task Selection), Constraint Checking, Data Output and Communications. SOA uses spacecraft trajectory information, planetary constants and spacecraft information provided by JPL Navigation.

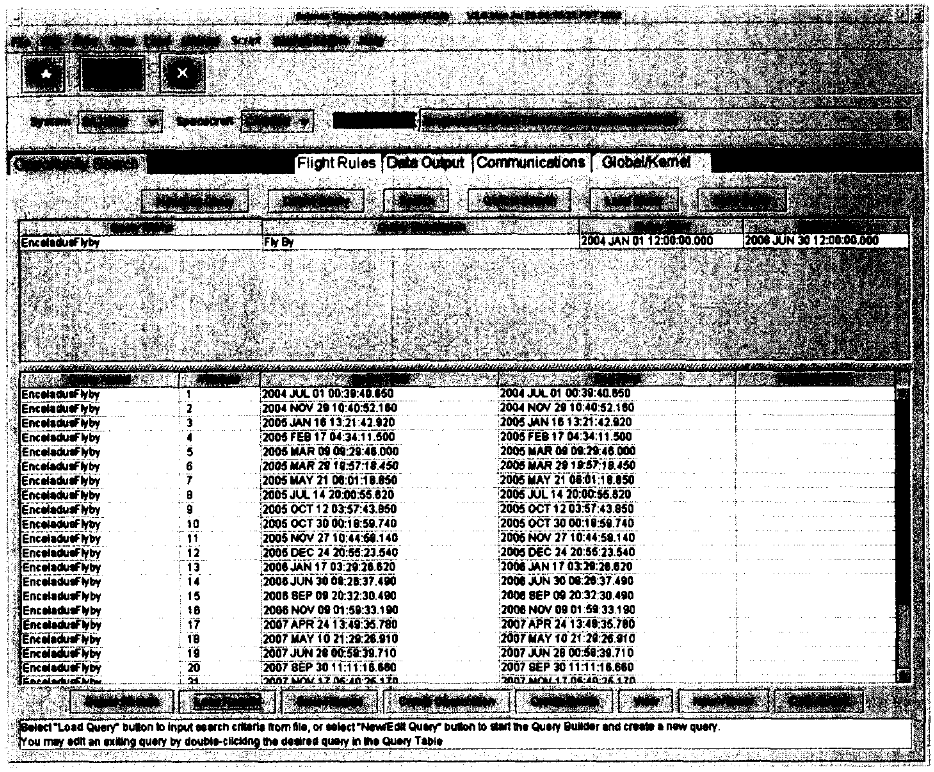

Figure 2.1 shows the Opportunity Search display. A search for a flyby of Enceladus has been performed and the time periods that met the search criterion are shown.

2.1 OPPORTUNITY SEARCH

In the user scenario above the first area the science user accesses is Opportunity Search. Opportunity Search allows the science user to identify times when a spacecraft is in a specific geometric relationship with other bodies in the solar system. This functional area allows the user to select from a list of more than thirty geometric search criteria including periapse times, apoapse times and various illumination geometries. These search criteria are based on continuous functions that can occur either at a specific time (for example, a certain distance from a celestial body) or over a time span (for example, an occultation). A search criterion can be created or entered from a file of previously created criteria. If the search criterion is new, the science user is presented with a drag and drop graphical user interface. The interface also displays a list of the information that is needed by that search criterion – called properties. The user enters the desired properties associated with the selected search criterion including the celestial bodies involved and other pertinent information such as angles or distance. A search criterion can be a simple single search or a more complex search combining multiple search criteria using Boolean operators of "and", "or", and "not". Once the search criterion is created and written to the list, the science user selects to have the software perform the search. The time periods when the geometric criteria have been satisfied are presented to the user in a list (see Figure 2.1).

SOA uses two search engines that have been created at Jet Propulsion Laboratory. Each of these search engines requires the input data to be entered a specific way. SOA has divided the Opportunity Search objects into two groups – the software models that contain the values for the Opportunity Search criterion properties and the templates that put the properties in the correct format for the chosen search engine. This scheme allows new search engines to be added easily, and for the search criterion to be easily changed. Finally, this scheme permits the objects to be discovered at runtime. "Discovery at runtime" means that SOA loads into the software only the objects that are available to be used. If a search criterion is not needed, then it is simply removed.

2.2 VISUALIZATION

Now that the science user has found the time(s) that match the geometric criteria, the next step is to look at a picture of the information. SOA allows the science user to select from several view options: 3 dimensional perspective projection, 3 dimensional arbitrary observer, 2 dimensional sky map and 2 dimensional trajectory plot. The perspective projection renders the view from the point of view of a specified observer looking at a target. Generally, the observer is a spacecraft and the target is a celestial body. The arbitrary observer view is a parallel projection that is rendered from an observer who can be arbitrarily placed in space by the user. The 2 dimensional sky map is an equidistant cylindrical map projection of the celestial sphere as viewed from the spacecraft. The 2 dimensional trajectory plot is a view of the spacecraft's trajectory around the target body. If the target body has satellites, this display also displays their orbits. This plot can show a view from either the ecliptic or the equatorial plane. The user can select items to be included in the picture such as: right ascension/declination (RA/Dec) grid, latitude/longitude grid, stars, magnetic field, planets, satellites, light/dark terminator, and other geometric information. If an item is not appropriate for a view, that selection is not made available to the user. For example, in the perspective view, the spacecraft trajectory can't be seen since the observer is generally the spacecraft itself. The selection to make it visible is not presented to the user. The user can also choose to see more than one view in a single window or multiple windows can be rendered with different views.

In Visualization the same hierarchical approach as Opportunity Search has been taken. The real world coordinates and formulas plus the characteristics of the real world entity form the software model objects. The actual Java 3-D constructs form the primitive objects. For example, an RA/Dec grid is comprised of a model object that has its properties of a line model, a text model, the grid spacing for both Right Ascension and Declination, the label spacing for both, etc. The associated primitive sets the Java 3-D appearance components and the properties for both the lines and the labels (i.e., line width, text font, etc.). This approach again allows a specific project to easily add, modify, customize or delete objects for that particular project. All of the objects are discovered at runtime.

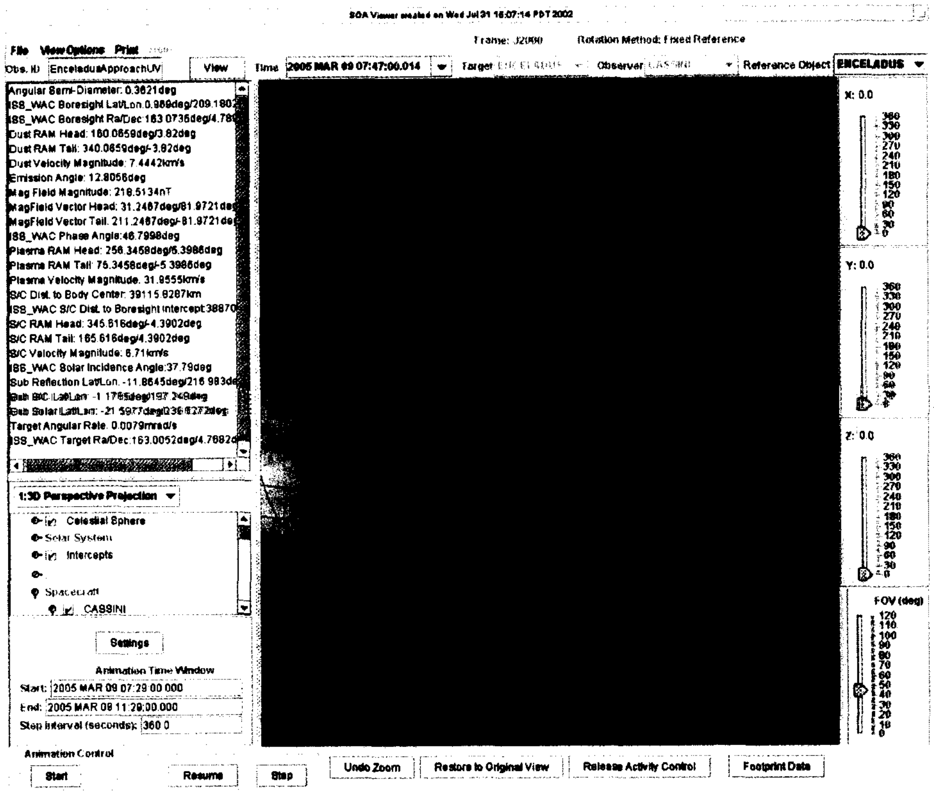

Figure 2.2 is a perspective projection of the closes approach of the Cassini spacecraft to Enceladus. The red square is a field of the view of a spectrograph projected onto the sky. It is red because it violates a constraint.

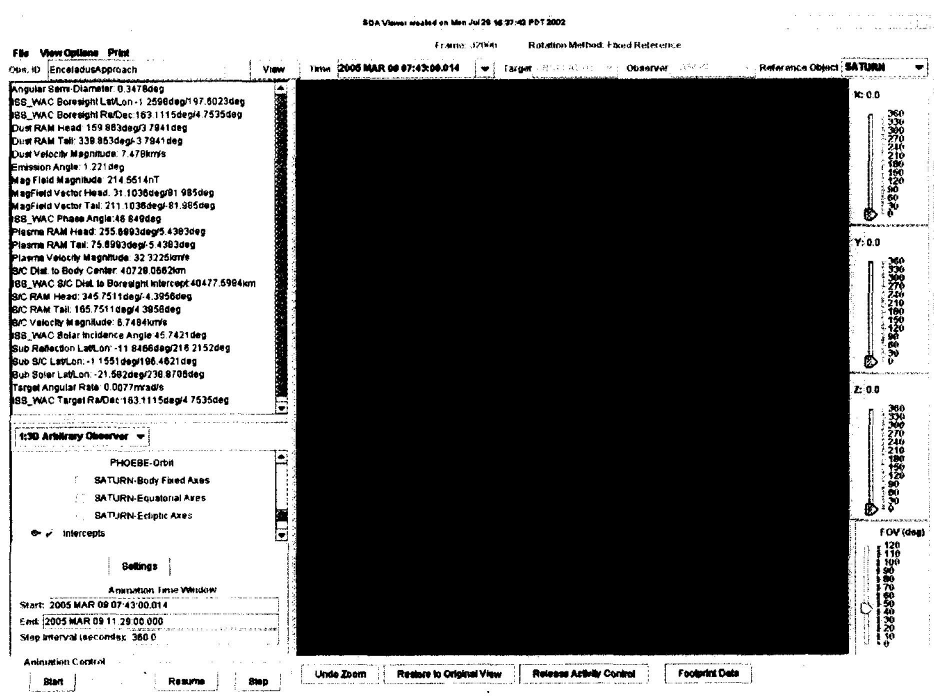

Figure 2.3 is an arbitrary observer view of the pole of Saturn. In this view the spacecraft trajectory is also shown. The lines originating at the spacecraft are various physical phenomena.

2.3 OBSERVATION DESIGN

Once the user sees a picture that conforms to the desired objectives, an observation design can be started. The science user can first choose to just look at the time and by specifying the spacecraft attitude, the user can see a display that shows the scene and also contains an instrument field of view. A field of view is an instrument aperture; generally they are squares, rectangles or circles. These fields of view can be projected onto the target – similarly to the way a person uses a camera with a viewfinder. This projection gives the scientist an idea of the coverage of the observation. Once the science user is satisfied with the coverage and the view, an observation type is selected.

The current choices are start-stop mosaic, continuous scan, roll about an axis, and stare. A start-stop mosaic consists of a set of pictures that are taken at a series of fixed spacecraft attitudes. The spacecraft or instrument platform or the instrument itself is moved to a location and waits while a picture is taken. This step is repeated until all the desired pictures are taken for the observation. A continuous scan is a series of measurements made at different pointing geometries while the spacecraft or instrument platform or the instrument itself is continuously moving. Roll about an axis is an observation that is performed while the spacecraft is rotating around a single axis. The stare observation is simply one that is performed while the spacecraft maintains a fixed attitude with respect to the target. Each observation type has properties that must be selected. There are general properties such as the target and observer that apply to all of the observation types.

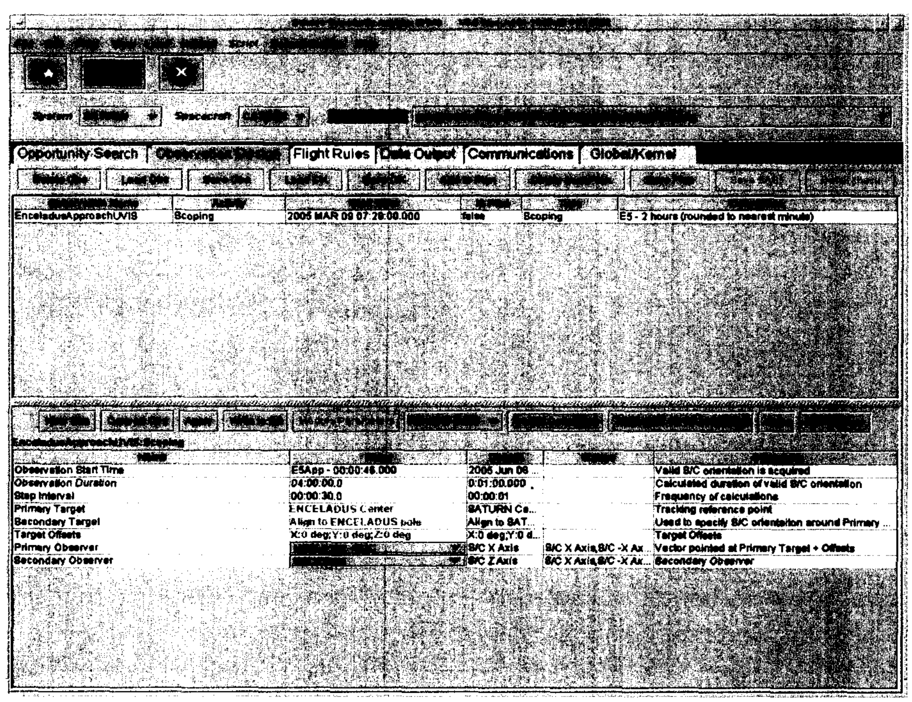

Figure 2.3 is the Observation Design display. The observation that is shown is an observation that simply specifies a time and a spacecraft attitude.

There are also properties that are specific to a particular type of observation such as the roll axis for a roll about an axis observation. Once the properties are selected, the user can choose to view the observation again with the new information that has been provided. At this point the scientist may want to animate the depiction to see how the scene changes over time. The user may review and change the properties and re-plot the depiction as many times as desired.

For Observation Design the software objects come in two flavors. The main object contains the information common to these observations like the start time and the target. The secondary object specifies the information that is specific for that type of observation, like the number of pictures to be taken. In addition to these objects, this area has objects that map the SOA observation properties to other tools such as the software that builds the plan of spacecraft activities. Most spacecraft missions have their own way of specifying observations and other spacecraft tasks (or activities). This area has a strong hierarchical component so that missions will have an easier time adding mission specific observations.

2.4 CONSTRAINT CHECKING

At this point if the science user has not already performed constraint checking on the observation, it is time to make sure that there are no constraint violations. The constraint violations are of two varieties. The first variety is the group of constraints that are geometric in nature. This group consists of various exclusion zones or impediments to performing the observation. An exclusion zone might be an angle that specifies a region where the Sun is too bright for an instrument or an area where another bright body is visible and may hurt a sensitive instrument. Sometimes it is not damaging to the instrument if the distance from the bright body places the instrument in a safe zone or if the exposure to the bright light is below a given threshold. The exclusion zone object has four variations. It can simply be an angle that must be excluded. It can be an angle with a distance attached. It can also be either of these two with an exposure time limit specified. Impediments may not be dangerous, but may cause the observation not to meet its objectives. An example of this case might be the occulting of the target body by another body or that another body is transiting across the target body in such a way as to spoil the observation. Currently, this type of violation hasn't been implemented. The second group consists of state violations. Examples of this type could be that the spacecraft maximum rates and/or accelerations are exceeded. The converse could also be true – the minimum rates and/or accelerations are not met. For either type of constraint, the user enters the required properties through the drag-and-drop user interface. If the user finds that the observation causes constraints to be violated, the observation can be modified and the process can begin again.

Flight rule/constraints consist of building blocks objects that can be combined to create the constraint rules. Each exclusion zone type has its own combined object. The drag-and-drop graphical user interface can be used to create the mission specific rules for exclusion zones. In addition, there are rate objects and acceleration objects. Since it is possible to have spacecraft rates, instrument platform rates and articulating instrument rates, the specific space mission can tailor these building blocks to their own needs also using the graphical user interface. The object hierarchy allows missions to add different types of rules that haven't been provided by SOA.

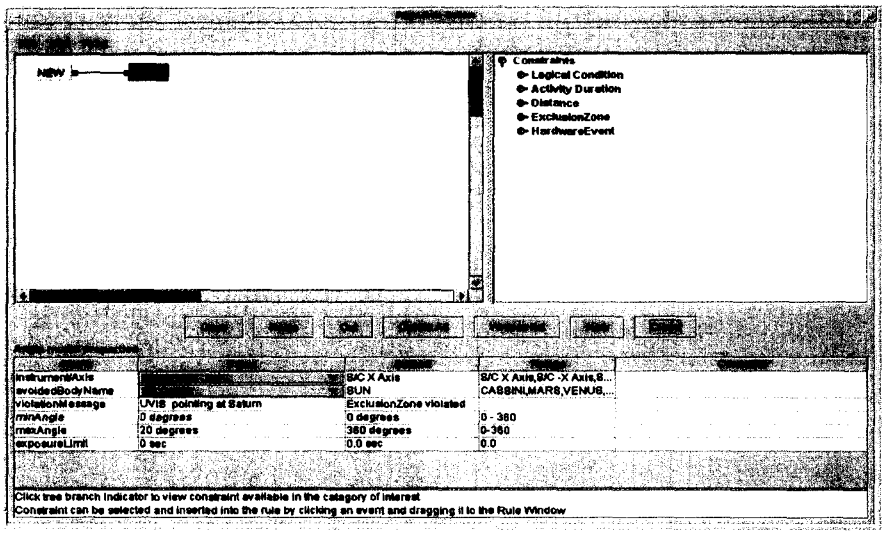

Figure 2.4 shows the Constraints rule builder with the angle exclusion zone selected.

2.5 DATA OUTPUT

Either before or after a design has been created, the user may want additional information about the spacecraft trajectory, opportunity search results or the observation to help to determine if an observation for this time period is viable and valuable. The Data Output tab allows the user to select the desired data and the form the data is to take. SOA allows the user to select to have the information put into tabular form that can be viewed by spreadsheet software or in graphical form. Some of the data options include phase angle or emission angle output, RAM vector information (such as the Magnetic Field Ram Vector), the sub-reflection point (i.e., the Sun's brightest point on the target), the sub-spacecraft point (i.e., the spacecraft's position projected onto the target body), angles between components on the spacecraft and celestial bodies, etc. For the graphical data output, the user can choose from the following types of plots: stacked plot, x/y individual plot, x/y/z plot, or an "all" in one plot The plot tool graphs selected values over time.

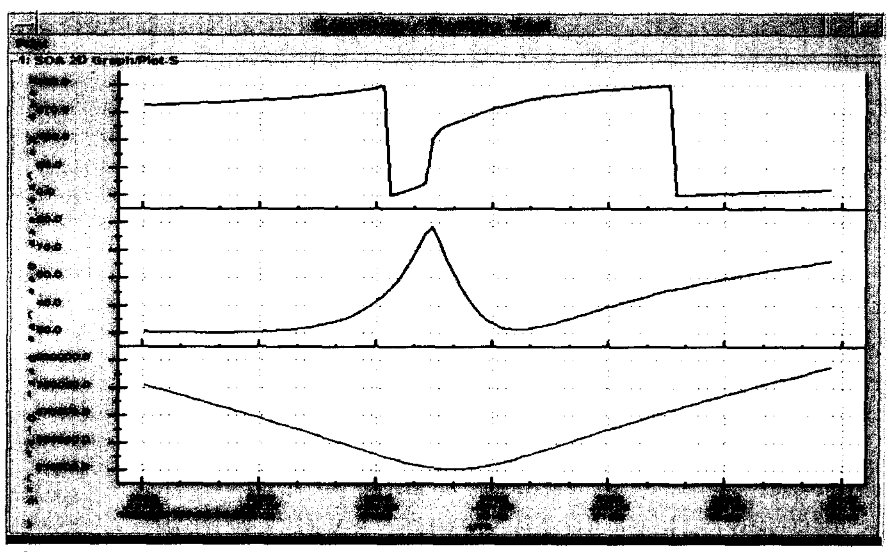
Figure 2.5 shows a spacecraft trajectory related stacked plot with graphs of the Magnetic Field Vector Right Ascension and Declination and the Cassini spacecraft distance to the center of Enceladus.

2.6 COMMUNICATIONS

The last task that the science user performs using SOA is to place the finished observation in the plan of activities with all of the other observations and the engineering tasks (like calibrations and maneuvers). SOA is the first tool designed to communicate with other tools used for developing the plan of activities for the spacecraft. In the past the scientist had to create the observation and then the information had to be re-entered into the software that would prepare it for the spacecraft. Now SOA communicates with that software either by using inter-process communications (IPC) or through the use of files. The planning software provides a visual timeline and resource consumption graphs. SOA communicates with this software tool using inter-process communication. Observations are sent directly to this software by simply pressing a button. Other legacy software requires input via files. SOA also creates these files so that they can be ingested into these legacy tools.

In addition to allowing the user the ability to send their observations designs to other software, SOA allows the user to share the observation information with other scientists. SOA can save the observation information in the form of a C-Kernel file (a binary file that contains quaternions for the spacecraft's attitude over time). The C-Kernel file is a relatively standard file used by many scientists and engineers in the space industry. By producing this file, SOA permits software applications written by others to ingest the observation information. C-Kernel files are maintained by the Planetary Data System Navigation and Ancillary Information Facility (NAIF) at JPL

Communication objects exist at two levels. The first level of objects contains the data that forms the observation. These objects have the properties for the observation and how those properties are to be translated to the planning software tools. The second level of objects contains the messages that are to be sent to the planning software through IPC. A corresponding set of objects contains the information on how to write the information to the files (the observation file and the C-kernel). Again, this separation allows projects to easily add or change the data or the format to meet their specific needs.

3.0 TECHNICAL CHALLENGES

Creating SOA with these capabilities has not been an easy task. When SOA began, Java 1.2 had not been released and Java 3-D had had only a few releases. There were performance issues, memory leaks (on the SOA side as well as the Java side), and questions of accuracy in the graphics presentation. In addition, translating the data so that it could be recognized by other software has been difficult in terms of making sure that apples were translated as apples and not as oranges. At this time Java and Java 3D have made significant advances and SOA has had the support of Java experts at Sun. Additionally, SOA has been supported by several members of the science community in overcoming obstacles. The end result is a reliable, stable SOA containing a wide variety of functional capabilities.

4.0 CONCLUSION

In conclusion, the approach that has been taken in creating SOA has been to keep the scientist in mind at all times. It began by collecting the science user's needs and proceeded by keeping this user involved throughout the project. The tool fills a void that has existed since science instruments were placed on a spacecraft. Many people have envisioned a tool of this nature. SOA is the beginnings of all those visions. Over time it will continue to improve to meet those expectations. But most importantly, SOA enables the scientist to create his/her observation easily.

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ACKNOWLEDGEMENTS

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rtunity Analyzer (SOA)

A Multi-Mission Tool

for Planning from

Services & Applications

Barbara Streiffert, Carol A. Polanskey, Taifun O'Reilly, and Joshua E. Colwell

Jet Propulsion Laboratory

Pasadena CA

Competing Characteristics

- Observations and measurements and the resulting data are the reason spacecraft are sent into space.
- Scientists want to utilize every possible opportunity to perform these experiments and retrieve as much data as possible.
- Some observations have the potential to put the spacecraft at higher risk.
- Engineers want to ensure the health and welfare of the spacecraft.

Solution: Provide scientists with a tool that allows them to plan their observations while adhering to the rules governing the safety of the spacecraft.

Background

- Scientists on spacecraft instrument teams need the ability to identify and design observations for their instruments.
- They generally do not want or have access to detailed spacecraft commanding software.
- SOA has been developed as a multi-mission science planning tool that allows scientists to design, check, and modify observations and feed those designs into the detailed uplink software system without having to use the entire uplink software system.
- Initial SOA design used Quality Functional Deployment to survey the user community to incorporate their requirements into the software requirements.
- SOA is java-based, and makes use of the JPL Navigation and Ancillary Information Facility (NAIF) SPICE software toolkit.

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What is SOA?

- **First tool a scientist/mission planner will use.**
  - –Identify key opportunities & check out the feasibility of potential observations.
  - –Easy to use by wide range of non-JPL science team members and support staff.
  - –Run on multiple platforms: SunOS, Windows, Linux.
  - –Based on standard NAIF/SPICE tools providing high fidelity.
- **Revisiting observation after changes to the "plan" can be done.**
  - –Retrieve new time window or validate observation following updates to the s/c trajectory.
  - –Communicates with other downstream sequence development software to validate observations following integration.

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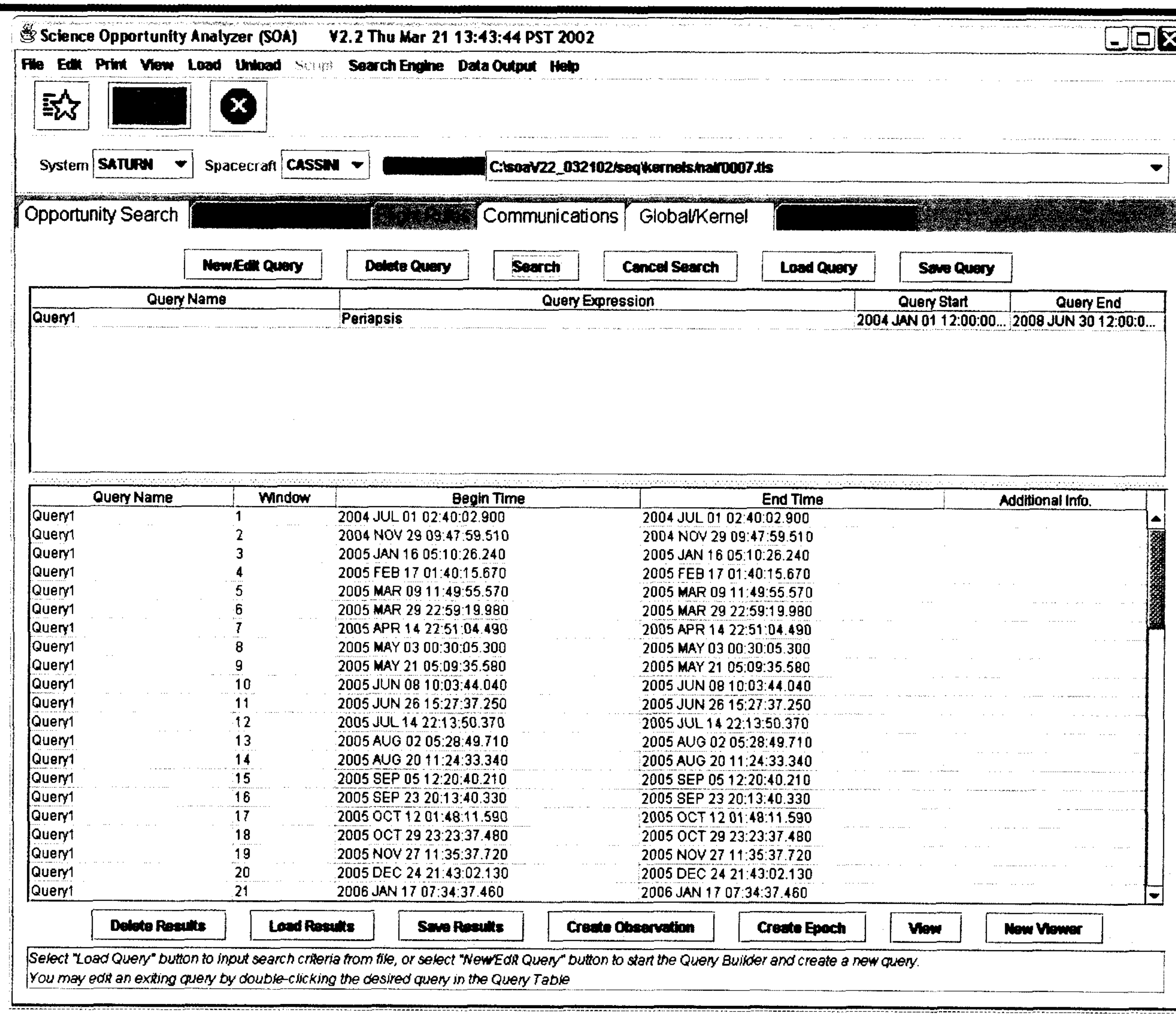
SOA is a Multi-Mission Tool

- SOA is configurable to a specific mission.
    - This process is called "adaptation". Adaptation adds the mission specific data for SOA to work with. This mission specific data will include flight rules, observation types, physical phenomena models, celestial body data, instrument data, spacecraft-specific data and a spacecraft trajectory. Much of this data can be provided through the use of JPL navigation files.
- SOA's first customer is the Cassini/Huygens mission to Saturn.
    - Examples in this presentation are for the Cassini mission. Cassini arrives at Saturn July 1, 2004, to begin a four year orbital "tour" of the Saturn system, including planet, rings, satellites, and magnetosphere. SOA is designed to handle observations of each of these diverse targets.

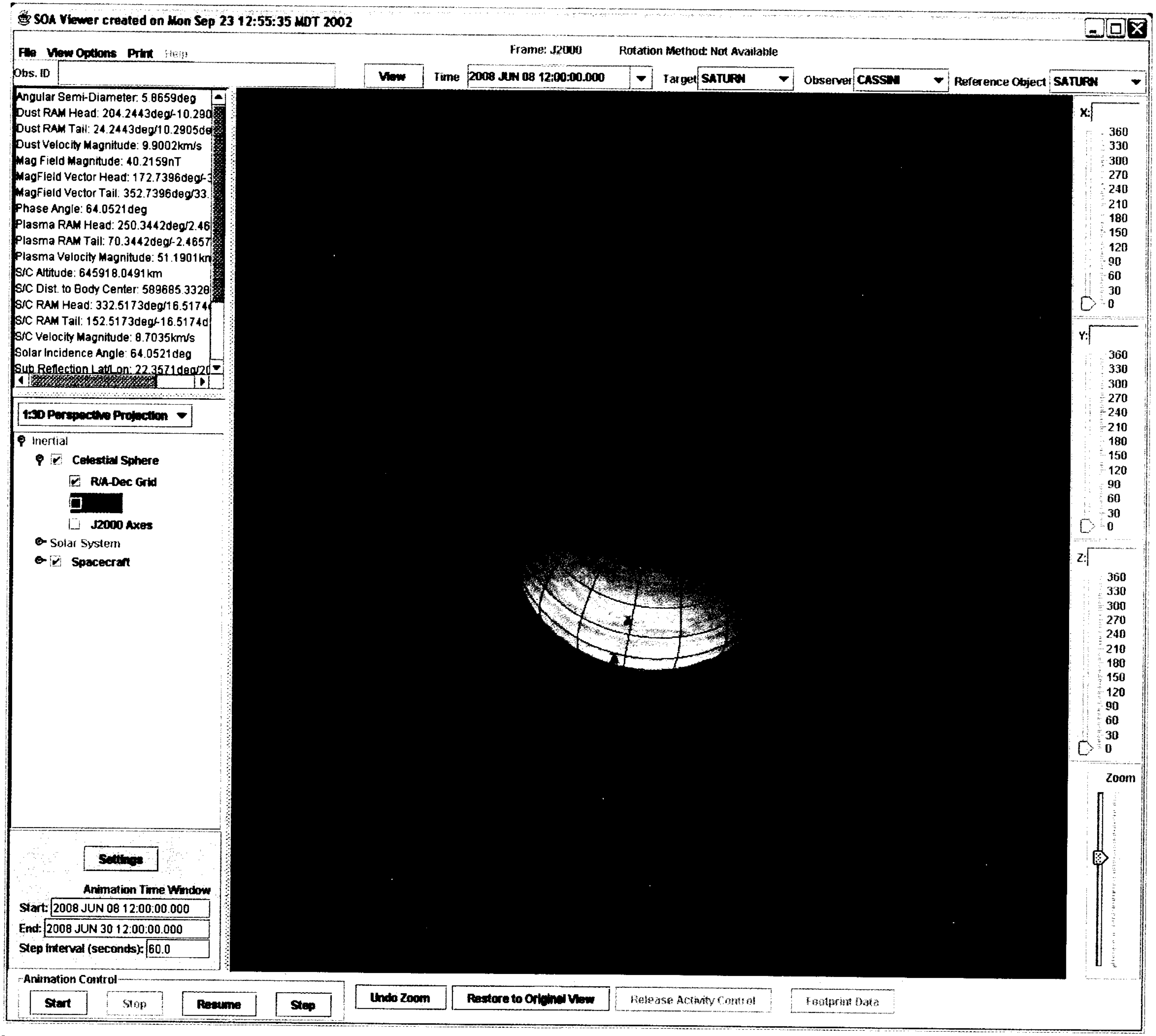
SOA Capabilities

- Visualization
  - Visualize the system in 3D and 2D from the point of view of any object in the system, including the spacecraft, or from an arbitrary point of view.
  - Visualze observations, with projections of instrument fields of view onto any object in the system, including observations designed in other software.
  - Animate the view for arbitrary times or for the period of an observation.
- Opportunity Search
  - Search for a science opportunity, i.e., one or more time “windows” when a science observation can occur (uses Percy and EVENTS search engines)
  - Use visualization to validate observation geometry.

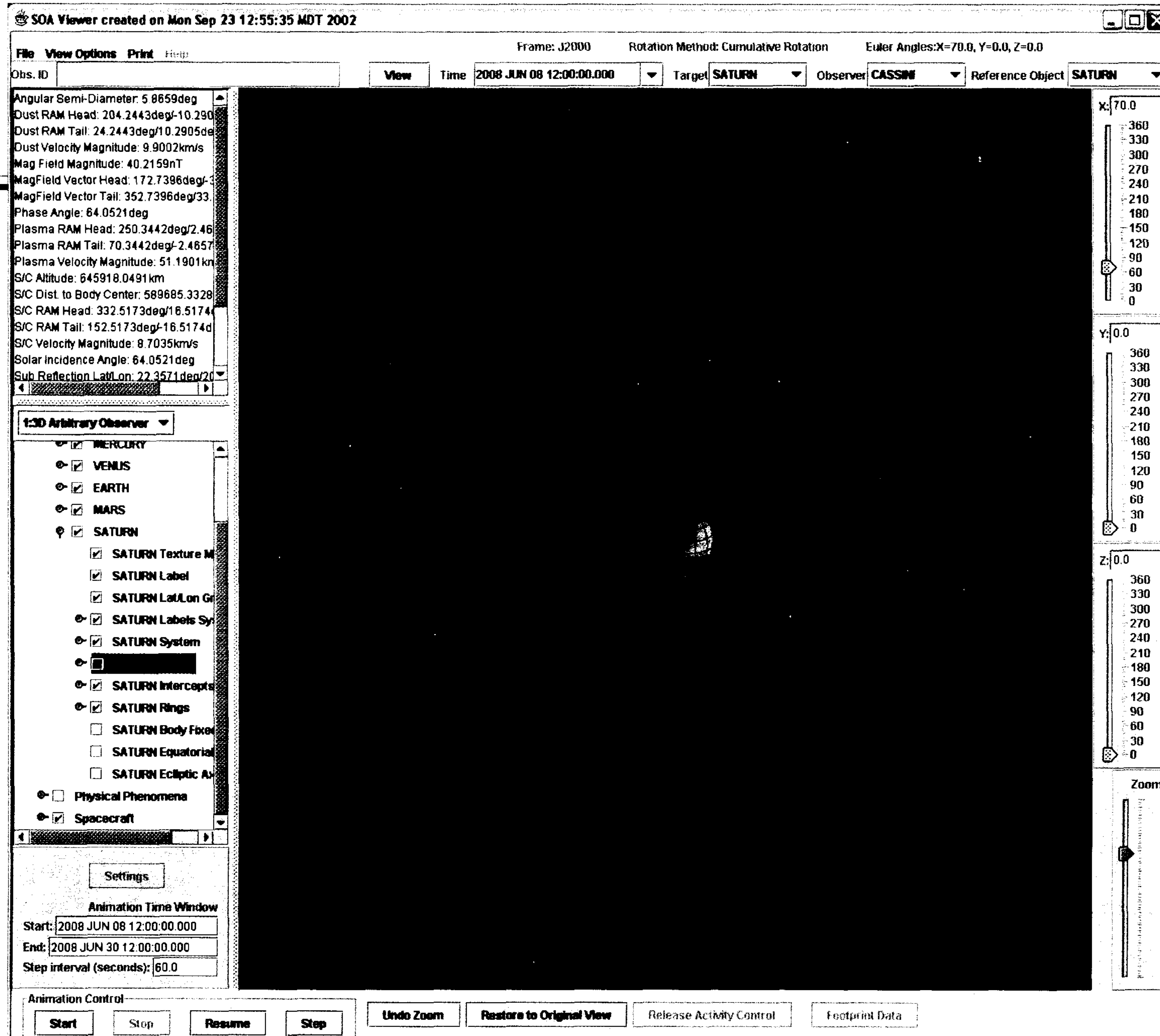
List of times when user-specified geometric criteria are met, returned by one of two opportunity search engines used by SOA: Percy and EVENTS.

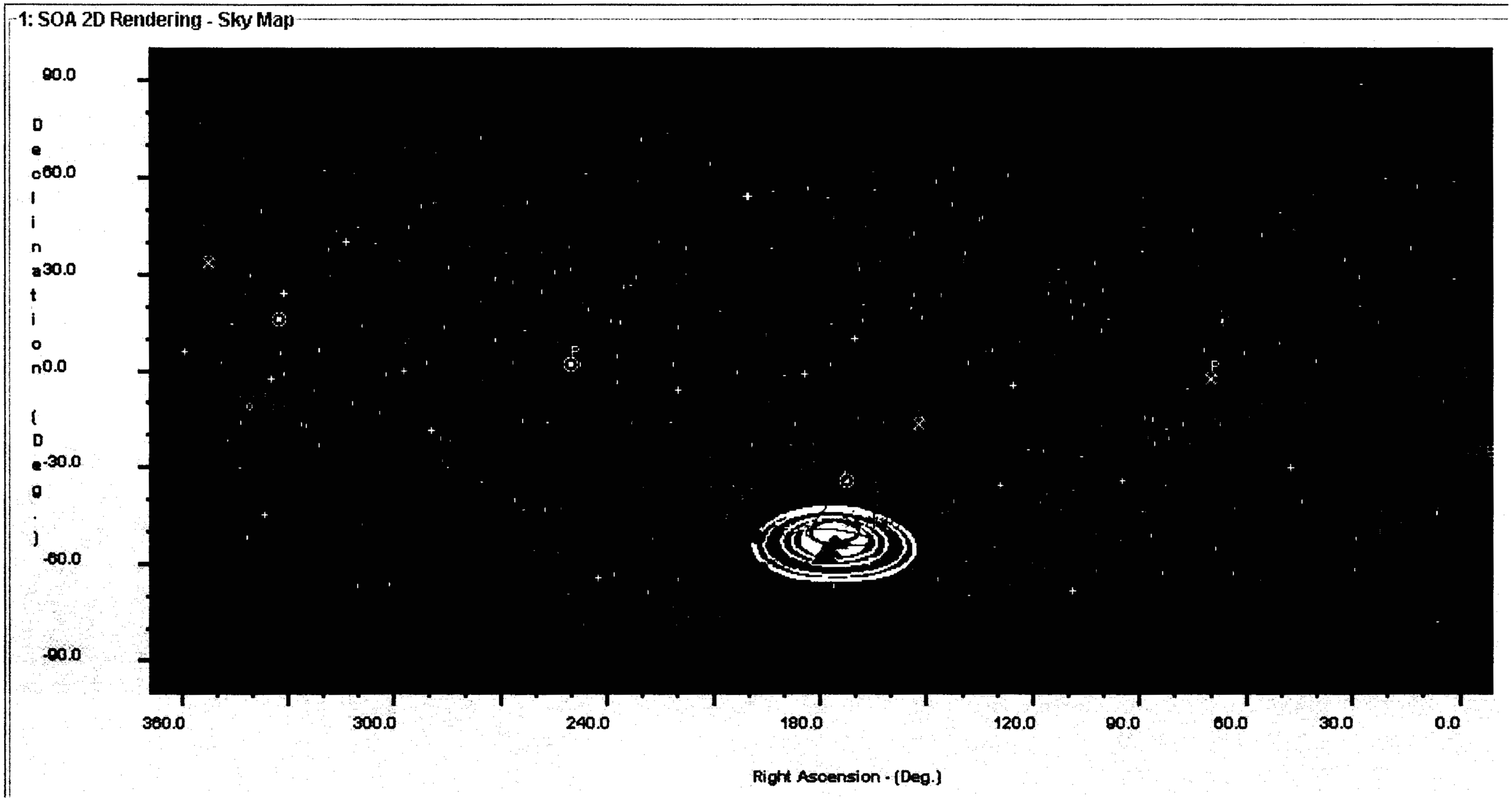


3D Perspective View of Saturn as seen from Cassini, June 2008



3D Perspective View of Saturn as seen from a user specified vantage point, June 2008. The Cassini spacecraft is visible at upper right, along with spacecraft and satellite trajectories.



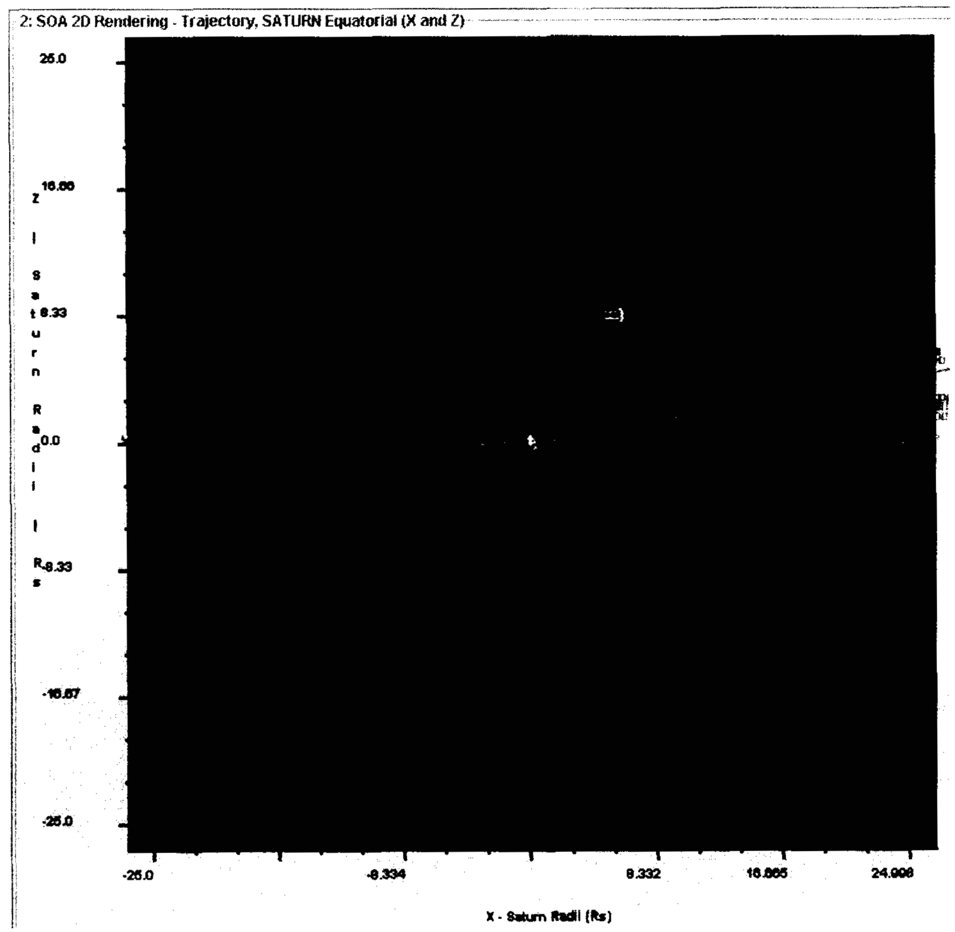


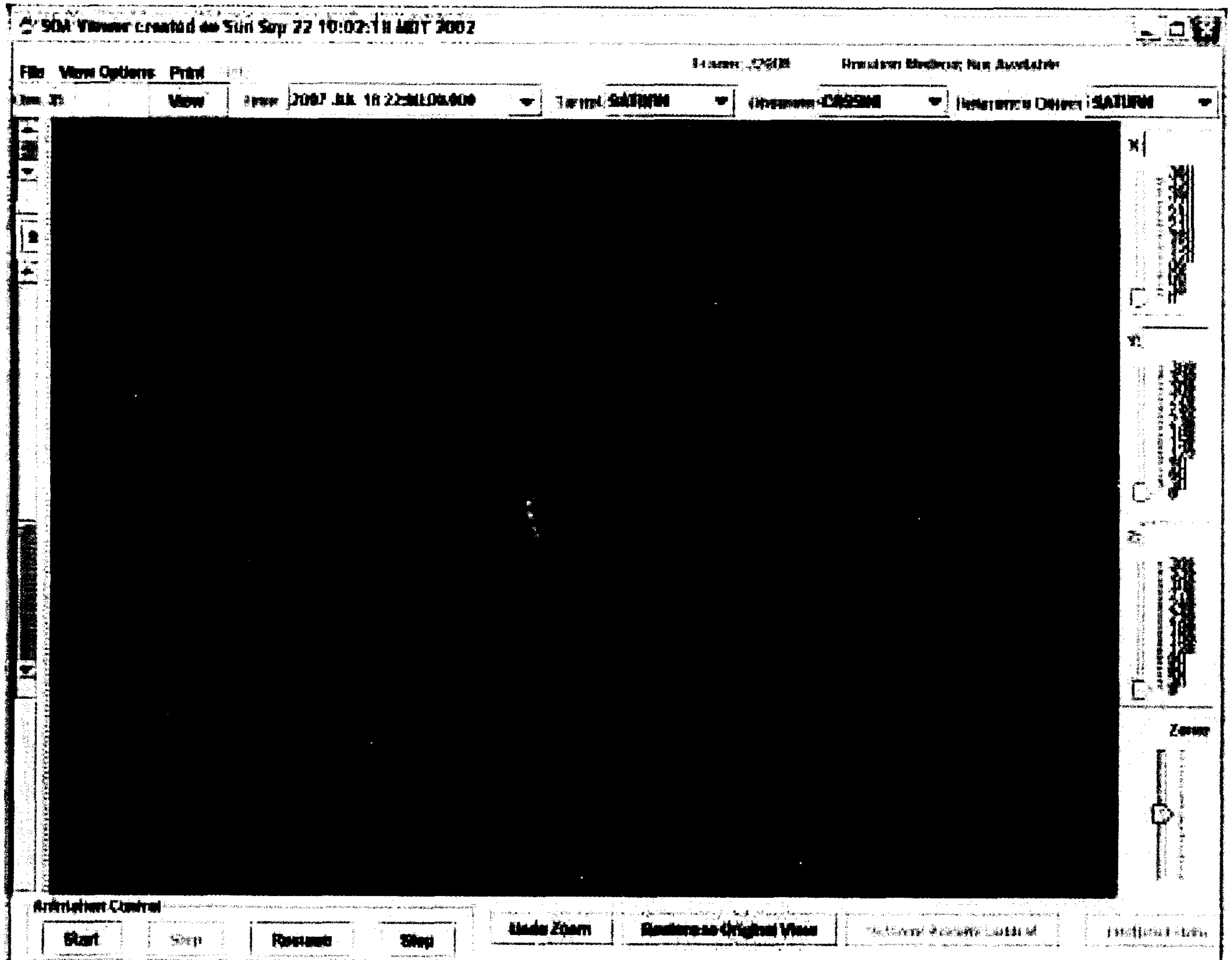
2D Sky Map at the same time, as seen from Cassini.

2D Trajectory View of the X-Z plane, with spacecraft and satellite trajectories shown. Time tick marks help the user identify times of interest for an observation.

Multiple viewers with various view types may be opened at one time.

All views may be animated and manipulated for zoom and rotation.

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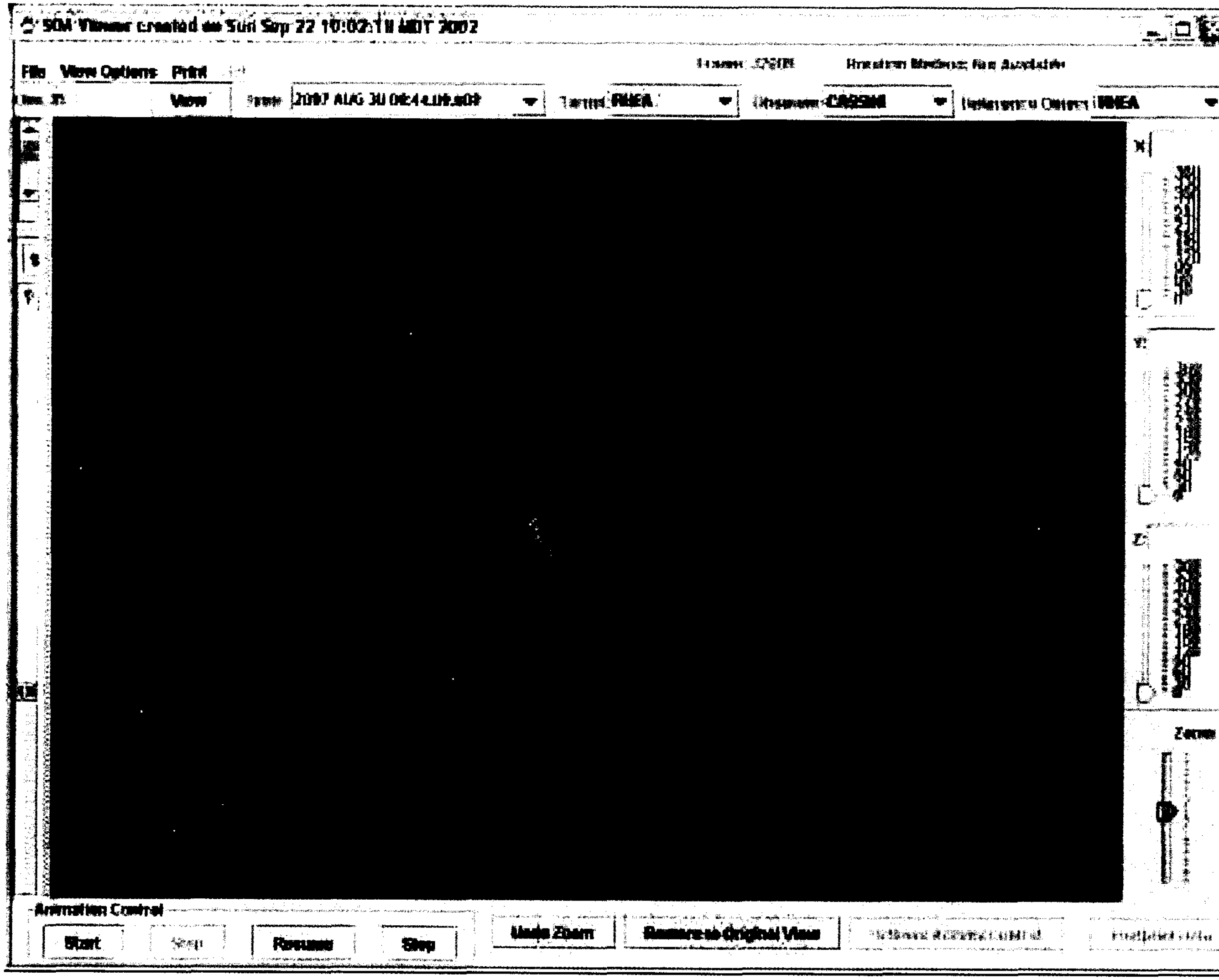
File View Options Print
View
Target: SATURN
Observer: CASSINI
Reference Object: SATURN
Zoom
Animation Control
Start
Step
Resume
Stop
Undo Zoom
Restore to Original View


File View Options Print
View
Animation Control
Start
Resume
Stop
Undo Zoom
Zoom

SOA Capabilities (cont.)

- Observation Design
  - Plan & design science observation(s) at the times(s) suggested by the opportunity search.
  - Scientist control and verification of observation parameters to ensure desired observation objectives will be met (exposure times, target coverage, observing geometry).
  - Detailed parameter control with mapping to spacecraft sequence generation software parameters.
  - High level "Scoping" design tool for "what if" studies.
- Constraint Checking
  - Checks high level observation design constraints early in the sequence development process.
  - Provides feedback on violations.
  - Permits user-level and project-level rule checking.

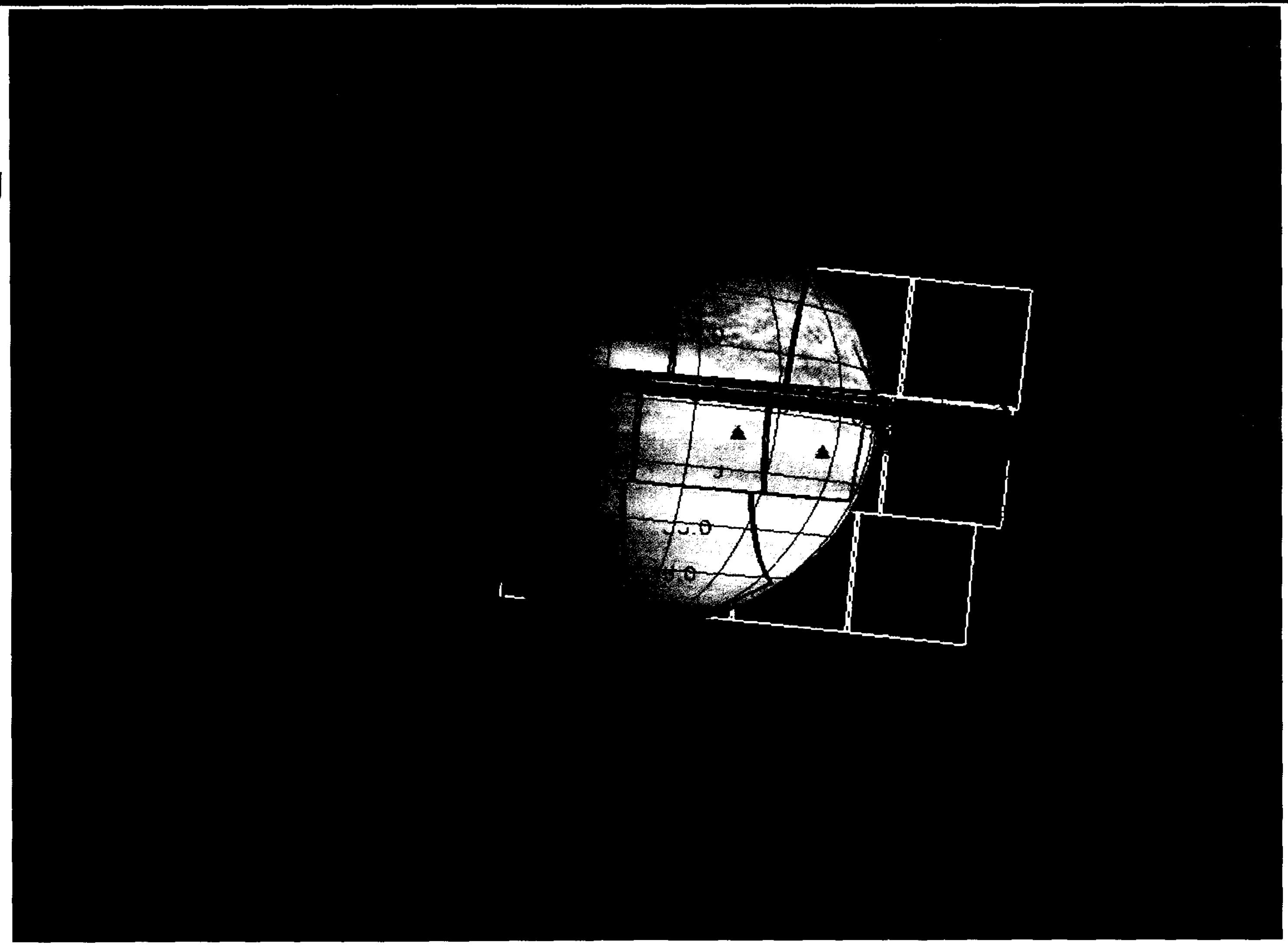
New Obs | Convert Obs | Apply | Write to list | Module Parameters | Nominal Twist | Check Constraint | no violations | View | New Viewer

New Observation:START_STOP_MOS

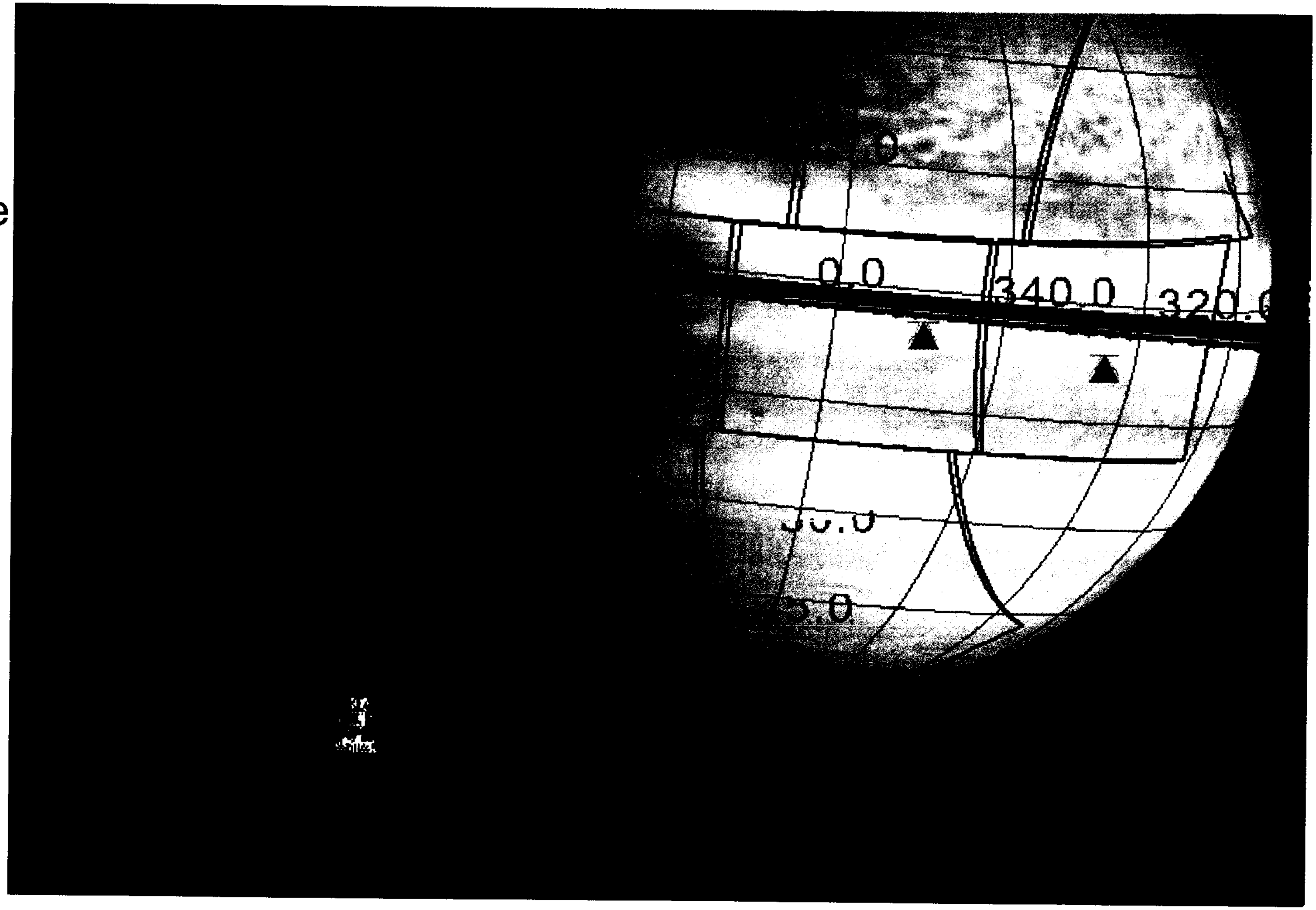
Name	Value	Default	Range	Comment
Activity Start Time	[redacted]	2005 Jun 08 ...		Time S/C starts to acquire target
Observation Start Time	2004 JAN 01 12:00:00.000	2005 Jun 08 ...		Valid S/C orientation is acquired
Observation End Time	[redacted]	2005 Jun 08 ...		Last time S/C orientation is maintained
Planned Duration	00:16:00.0	00:16:00.0		Total time allocated for the activity
Activity Duration	[redacted]	00:00:01		Total time calculated from parameters
Targeting Allowance	0:05:00.000	0:05:00.000		Time to acquire target S/C attitude
Targeting Margin	0:05:00.000	0:05:00.000		Margin applied to Targeting Allowance
Observation Duration	[redacted]	0:01:00.000		Calculated duration of valid S/C orientation
Observation Margin	0:05:00.000	0:05:00.000		Observation Margin
Step Interval	00:00:01	00:00:01		Frequency of calculations
Primary Target	SATURN Center	SATURN Cen...		Tracking reference point
Secondary Target	Align to SATURN pole	Align to SATU...		Used to specify S/C orientaiton around Primary ...
Target Offsets	X:0 deg;Y:0 deg;Z:0 deg	X:0 deg;Y:0 d...		Target Offsets
Primary Observer	S/C X Axis	S/C X Axis	S/C X Axis,S/C -X Axi...	Vector pointed at Primary Target + Offsets
Secondary Observer	S/C Z Axis	S/C Z Axis	S/C X Axis,S/C -X Axi...	Secondary Observer
Mosaic Specification	Flyback;1per strip;1 total; angles ...	Flyback;1per ...		Detailed mosaic parameters
Target Motion Compensation	OFF	OFF	ON,OFF	Tracking of the target during observation

Observation design screen of SOA allows the user to specify the time, duration, target, instrument, and style of observation. Additional input screens accept detailed mosaic information.

Example mosaic showing the footprints of the Cassini Wide Angle Camera. Pink footprints indicate intercepts on the target body. Yellow footprints show the pointing in inertial space.



The same mosaic viewed from outside the spacecraft. Here, scientists can see the orientation of the spacecraft for possible secondary measurements.

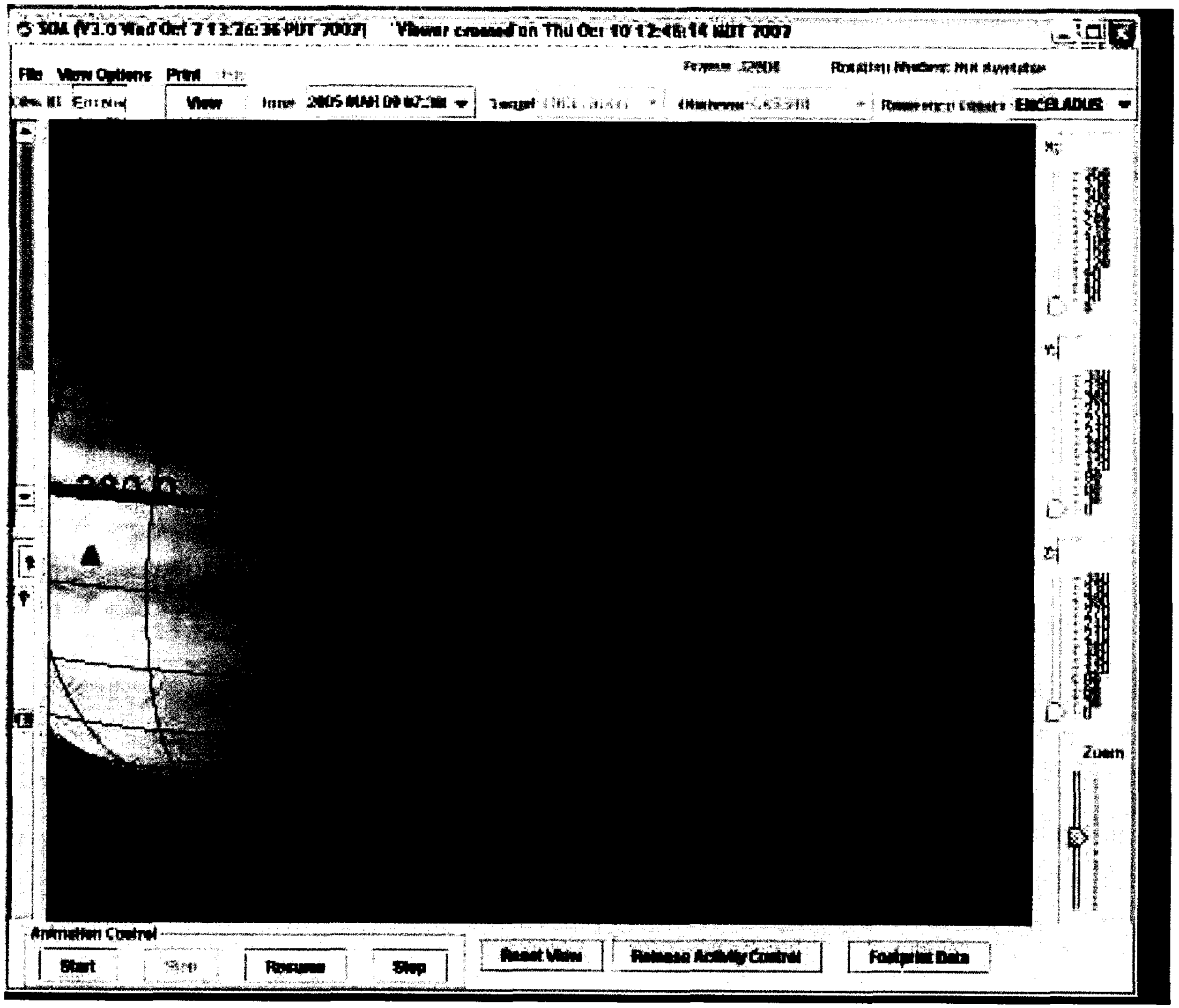


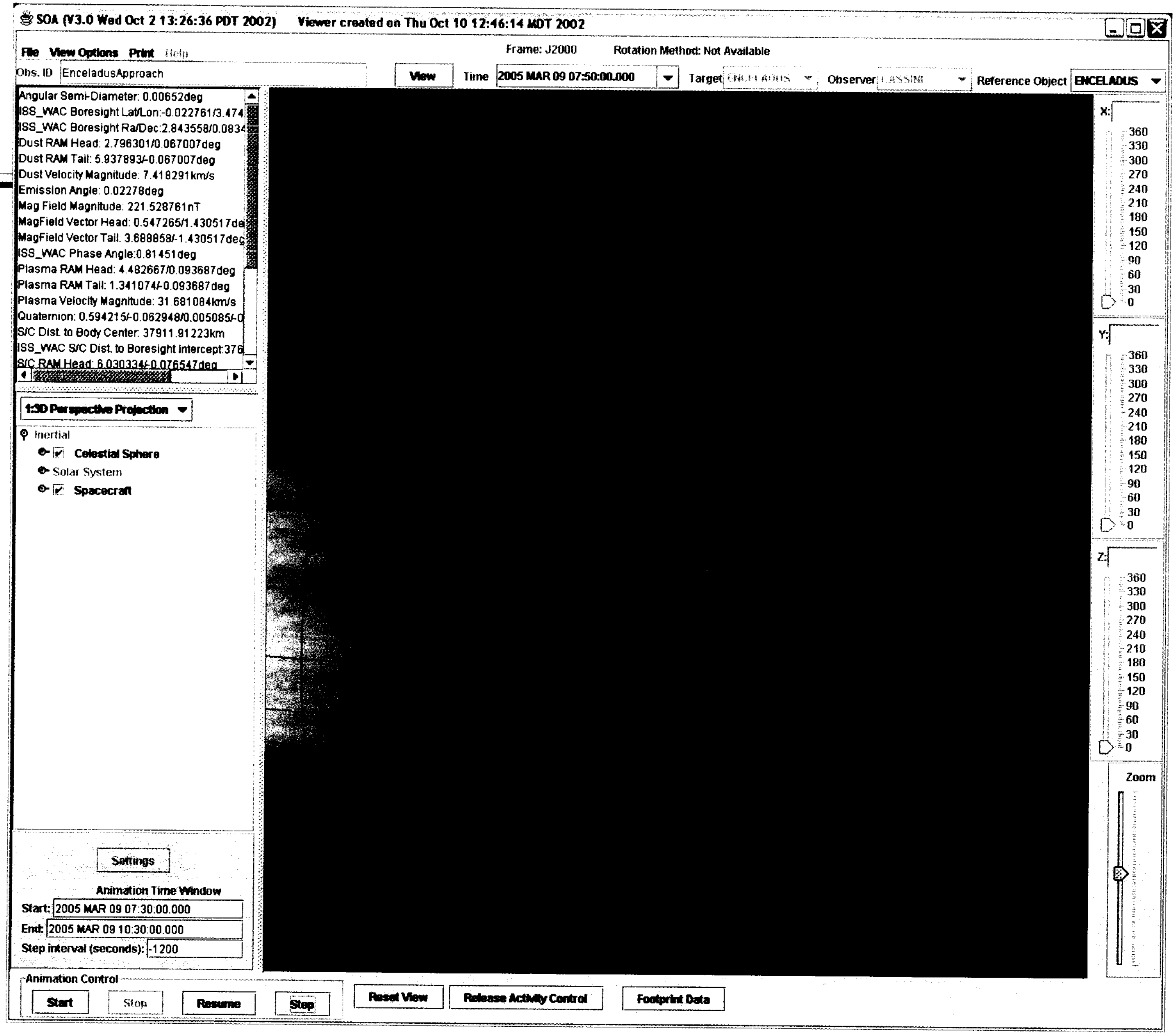
Opportunity Search | [redacted] | Flight Rules | Data Output | Communications | Global/Kernel | [redacted]

Default Activity Rules: **All On** | **New/Edit Rule** | **Delete Rule** | **Load Rules** | **Save Rules**

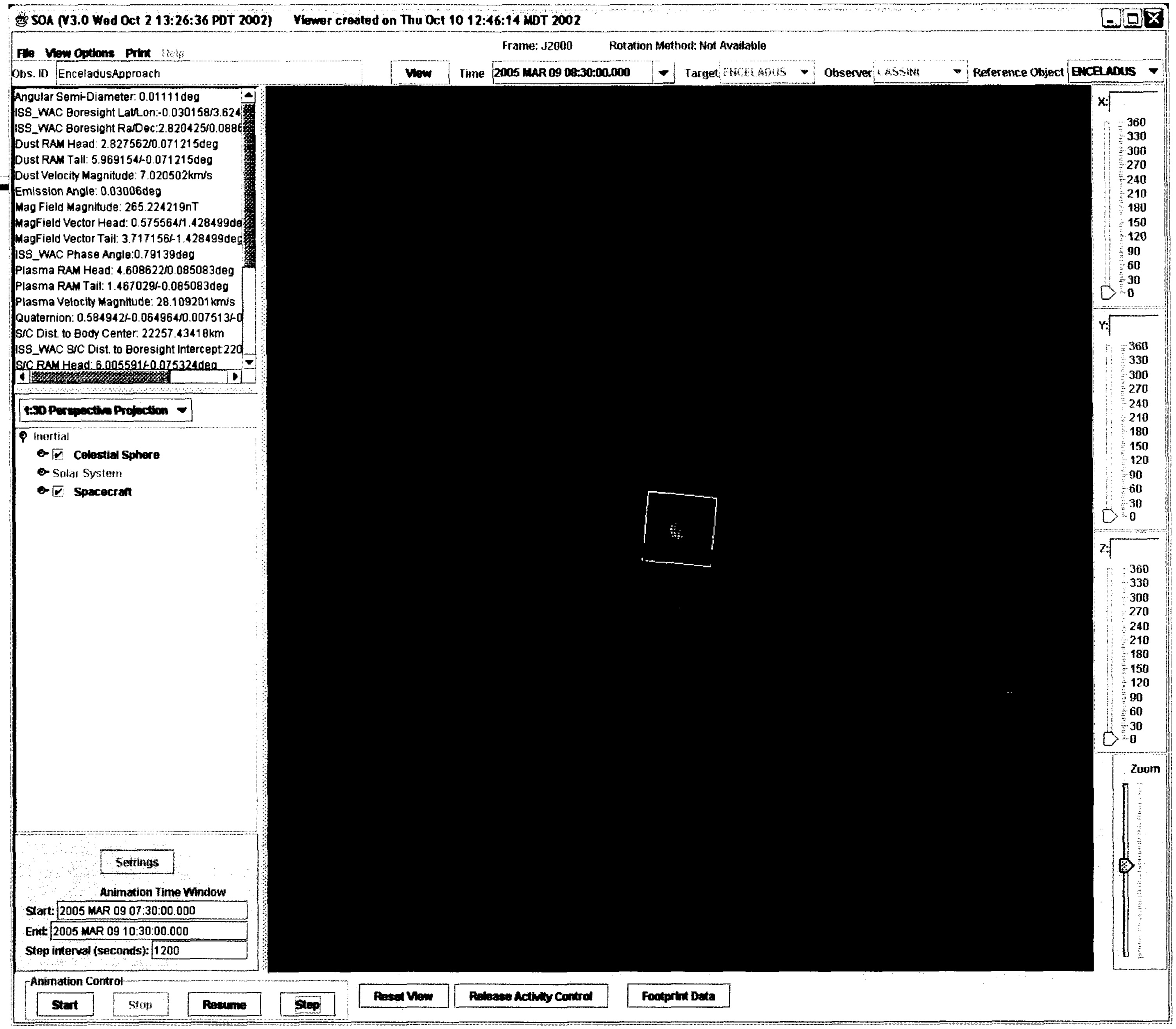
Rule Name	Enabled	Rule Expression	Description
AngleTest	☐	Angle	ISS WAC 5 deg of Sun
AngleTest20min	☑	Angle	ISS WAC 5 deg of Sun for 20 min
AngleTest30min	☐	Angle	ISS WAC 5 deg of Sun for 30 min
AngleASDTest	☐	Angle + ASD	ISS NAC 2 deg of Saturn
AngleASDTest2hr	☐	Angle + ASD	ISS NAC 2 deg of Saturn for 2 hours
AngleASDTest1day	☐	Angle + ASD	ISS NAC 2 deg of Saturn for 1 day
AngleASDTest2day	☐	Angle + ASD	ISS NAC 2 deg of Saturn for 2 day
AngleDistanceTest1	☐	Angle + Distance	ISS WAC 5 deg of Sun from 4-5 AU
AngleDistanceTest2	☑	Angle + Distance	ISS WAC 5 deg of Sun from 5-12 AU
AngleASDTest2	☐	Angle + ASD	ISS NAC between 2 & 4 deg of Saturn
AngleASDTest3	☐	Angle + ASD	ISS NAC between 4 & 6 deg
AngleASDDistanceTest1	☑	Angle + ASD + Distance	ISS NAC 2 deg of Saturn & Cassini within 1 million km
AngleASDDistanceTest2	☐	Angle + ASD + Distance	ISS NAC 2 deg of Saturn & Cassini between 1-5 million km
AngleASDDistanceTest3	☐	(Angle + ASD AND Distance)	ISS NAC 2 deg of Saturn s/c between 4-5 AU
AngleASDDistanceTest4	☐	(Angle + ASD AND Distance)	ISS NAC 2 deg of Saturn s/c between 5-12 AU
CompoundAngleTest	☑	(Angle OR Angle OR Angle)	ISS WAC multiple Sun conditions
FR07B4	☑	Angle + ASD + Distance	
rateTest1	☑	TurnRate	max rate = 0.0016 rad/s (default)
accelTest1	☑	**TurnAccel**	**max accel = 1.0E-5 rad/s/s (default)**
rateTest2	☐	TurnRate	max rate = 0.0001 rad/s
accelTest2	☐	TurnAccel	max accel = 10 rad/s/s
accelTest3	☐	TurnAccel	max accel = 8.0E-6 rad/s/s
ruleTest1	☑	Angle + ASD	ISS WAS RAD sun constraint

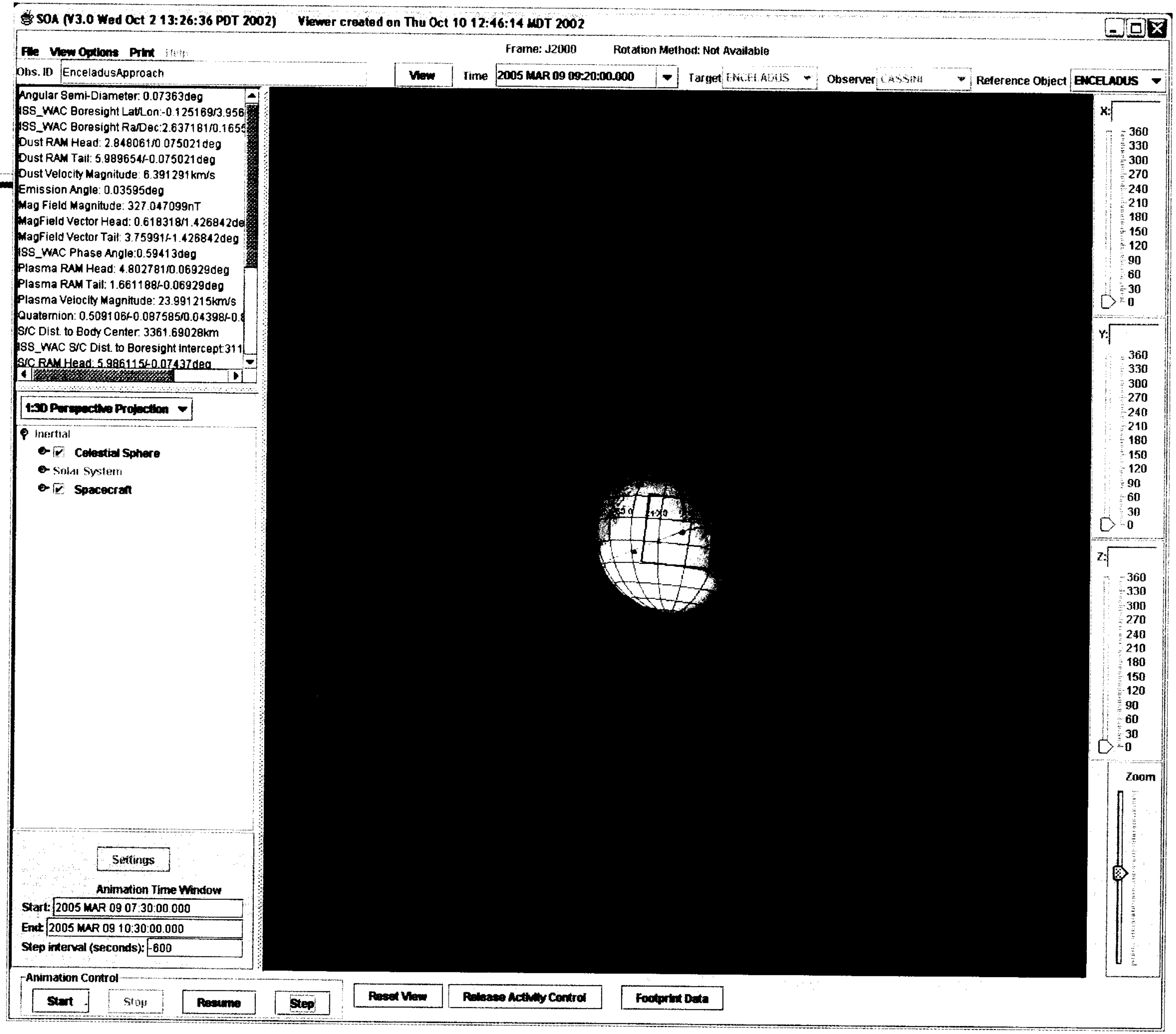
The constraint checking screen of SOA allows the user to define and control constraints that observations must meet. All violations of these constraints are identified by SOA in a time-ordered listing generated on the observation design screen.


File View Options Print
View
Zoom
Animation Control
Start
Resume
Stop
Reset View
Release Activity Control
Footprint Data



SOA (V3.0 Wed Oct 2 13:26:36 PDT 2002) Viewer created on Thu Oct 10 12:46:14 MDT 2002
File View Options Print Help
Frame: J2000
Rotation Method: Not Available
Obs. ID EnceladusApproach
View
Time 2005 MAR 09 07:50:00.000
Target
Observer
Reference Object ENCELADUS
Angular Semi-Diameter: 0.00652deg
ISS_WAC Boresight Lat/Lon:-0.022761/3.474
ISS_WAC Boresight Ra/Dec:2.843558/0.0834
Dust RAM Head: 2.796301/0.067007deg
Dust RAM Tail: 5.937893/-0.067007deg
Dust Velocity Magnitude: 7.418291km/s
Emission Angle: 0.02278deg
Mag Field Magnitude: 221.528761nT
MagField Vector Head: 0.547265/1.430517deg
MagField Vector Tail: 3.688858/-1.430517deg
ISS_WAC Phase Angle:0.81451deg
Plasma RAM Head: 4.482667/0.093687deg
Plasma RAM Tail: 1.341074/-0.093687deg
Plasma Velocity Magnitude: 31.681084km/s
Quaternion: 0.594215/-0.062948/0.005085/-0
S/C Dist. to Body Center: 37911.91223km
ISS_WAC S/C Dist. to Boresight Intercept:376
S/C RAM Head: 6.030334/-0.076547deg
1:3D Perspective Projection
Inertial
Celestial Sphere
Solar System
Spacecraft
Settings
Animation Time Window
Start: 2005 MAR 09 07:30:00.000
End: 2005 MAR 09 10:30:00.000
Step interval (seconds): -1200
Animation Control
Start
Stop
Resume
Step
Reset View
Release Activity Control
Footprint Data
X:
Y:
Z:
360
330
300
270
240
210
180
150
120
90
60
30
0
Zoom


SOA (V3.0 Wed Oct 2 13:26:36 PDT 2002) Viewer created on Thu Oct 10 12:46:14 MDT 2002
File View Options Print Help
Frame: J2000
Rotation Method: Not Available
Obs. ID EnceladusApproach
View
Time 2005 MAR 09 08:30:00.000
Target ENCELADUS
Observer CASSINI
Reference Object ENCELADUS
Angular Semi-Diameter: 0.01111deg
ISS_WAC Boresight Lat/Lon:-0.030158/3.624
ISS_WAC Boresight Ra/Dec:2.820425/0.0886
Dust RAM Head: 2.827562/0.071215deg
Dust RAM Tail: 5.969154/-0.071215deg
Dust Velocity Magnitude: 7.020502km/s
Emission Angle: 0.03006deg
Mag Field Magnitude: 265.224219nT
MagField Vector Head: 0.575564/1.428499de
MagField Vector Tail: 3.717156/-1.428499deg
ISS_WAC Phase Angle:0.79139deg
Plasma RAM Head: 4.608622/0.085083deg
Plasma RAM Tail: 1.467029/-0.085083deg
Plasma Velocity Magnitude: 28.109201km/s
Quaternion: 0.584942/-0.064964/0.007513/-0
S/C Dist. to Body Center: 22257.43418km
ISS_WAC S/C Dist. to Boresight Intercept:220
S/C RAM Head: 6.005591/-0.075324deg
1:3D Perspective Projection
Inertial
Celestial Sphere
Solar System
Spacecraft
Settings
Animation Time Window
Start: 2005 MAR 09 07:30:00.000
End: 2005 MAR 09 10:30:00.000
Step interval (seconds): 1200
Animation Control
Start
Stop
Resume
Step
Reset View
Release Activity Control
Footprint Data
X:
Y:
Z:
360 330 300 270 240 210 180 150 120 90 60 30 0
Zoom

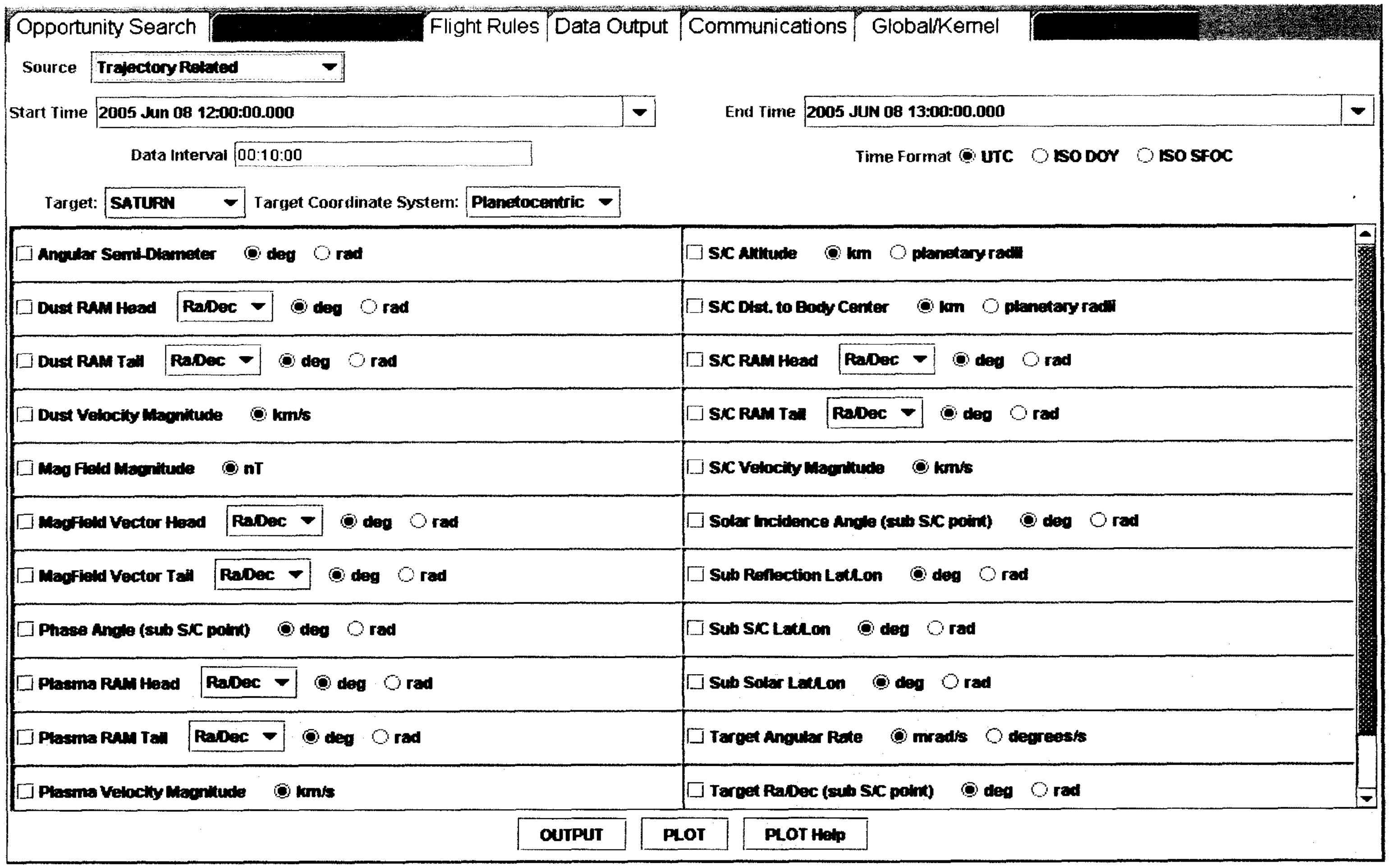

SOA (V3.0 Wed Oct 2 13:26:36 PDT 2002) Viewer created on Thu Oct 10 12:46:14 MDT 2002
File View Options Print Help
Frame: J2000
Rotation Method: Not Available
Obs. ID EnceladusApproach
View
Time 2005 MAR 09 09:20:00.000
Target ENCELADUS
Observer CASSINI
Reference Object ENCELADUS
Angular Semi-Diameter: 0.07363deg
ISS_WAC Boresight Lat/Lon:-0.125169/3.956
ISS_WAC Boresight Ra/Dec:2.637181/0.1655
Dust RAM Head: 2.848061/0.075021deg
Dust RAM Tail: 5.989654/-0.075021deg
Dust Velocity Magnitude: 6.391291km/s
Emission Angle: 0.03595deg
Mag Field Magnitude: 327.047099nT
MagField Vector Head: 0.618318/1.426842de
MagField Vector Tail: 3.75991/-1.426842deg
ISS_WAC Phase Angle:0.59413deg
Plasma RAM Head: 4.802781/0.06929deg
Plasma RAM Tail: 1.661188/-0.06929deg
Plasma Velocity Magnitude: 23.991215km/s
Quaternion: 0.509106/-0.087585/0.04398/-0.8
S/C Dist. to Body Center: 3361.69028km
ISS_WAC S/C Dist. to Boresight Intercept:311
S/C RAM Head: 5.986115/-0.07437deg
1:3D Perspective Projection
Inertial
Celestial Sphere
Solar System
Spacecraft
Settings
Animation Time Window
Start: 2005 MAR 09 07:30:00.000
End: 2005 MAR 09 10:30:00.000
Step interval (seconds): 600
Animation Control
Start
Stop
Resume
Step
Reset View
Release Activity Control
Footprint Data
X:
Y:
Z:
Zoom

SOA Capabilities (cont.)

- Communications
  - Communicate opportunity & design results to other software tools in the uplink process.
    - Reads and writes the standard Spacecraft Activity Sequence File (SASF) format
    - Interaction with Activity Plan Generator (APGEN) timeline software to work within the "science plan."
    - Interaction with Seq_Pointer (simulates actual spacecraft hardware and software) for more detailed constraint checking.
    - Interaction with Seq_Gen (generates uplink files) to become part of the official sequence product.
  - First SEQ tool to be designed from the beginning to communicate with other tools.

SOA Capabilities (cont.)

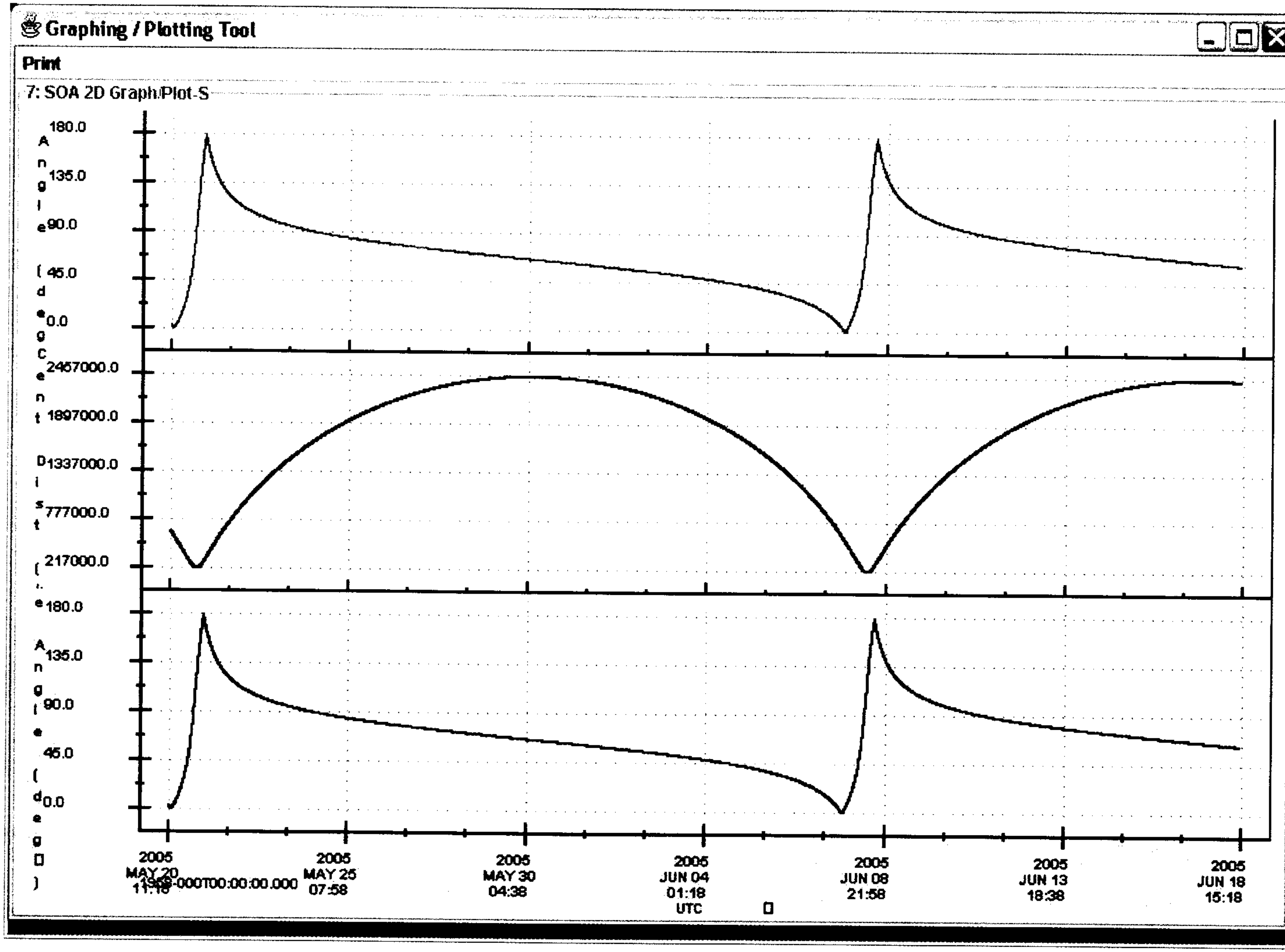
- Ancillary Data Output
  - Generate data files with geometric information as a function of time with user-customized parameter list for any period of time, or for an observation.
  - Plot ancillary geometric data for any period of time.
  - Provides complementary method for identifying observation opportunities and for validating geometry for designed observations.



Select or customize ancillary data for plotting or file output.

Example of stacked plot of ancillary geometric data:

phase angle, solar incidence angle, and distance from Saturn as functions of time.



SOA's Present and Future

- **Current Mission Support**
  - SOA is being used by the Cassini project, an international planetary spacecraft with a four year orbital tour at Saturn beginning July 1, 2004. Cassini scientists have been involved in detailed tour planning for more than 6 years. SOA is making observation design and planning more efficient in a time-constrained mission environment.
  - SOA's ability to show the same information in multiple ways (multiple visualization formats, data plots, listings, and file output) are essential when meeting the needs of a broad and diverse user community such as the Cassini Science Group.
- Multi-Mission Design
  - SOA is designed for use with any space mission. Project-specific capabilities are added to the core software as needed in the adaptation step.